A "STORMY" SORTIE FOR PRISTINE ROCKS IN LUNAR SOILS: 1. TRACE-ELEMENT COMPOSITIONS OF BASALTS AND IMPACT MELTS FROM APOLLO 12.

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We have analyzed the trace-element compositions of twenty-six >1 mm igneous fragments from Apollo 12 soil 12001. Of these 26 fragments, 16 have been determined to be fine-grained basalts or impact melts [1] and are presented here. We have identified five "new" pristine ilmenite-basalts, two pristine pigeonite-basalts, one olivine-basalt, two ilmenite-basalt impact melts, two KREEPy basaltic impact melts, and four impact melts of mixed derivation.

INTRODUCTION -- In order to understand the full diversity of volcanism on the eastern near-side of the Moon, we have studied 1-4 mm igneous fragments from Apollo 11 and Apollo 12 lunar soils. We began this survey and study in July of 1993 with hand-picking at NASA-JSC. Subsequently, we have analyzed these igneous rocks petrographically, determined their mineral chemistry, and determined their bulk major- and minor-element chemistry [1-4]. The data collection for this study is completed with this report and a companion report on the Apollo 11 samples [5]. In total, we have analyzed over 64 igneous rock fragments, and have discovered nearly thirty "new", pristine mare basalts from the eastern lunar near-side.

TRACE-ELEMENT COMPOSITIONS OF IGNEOUS FRAGMENTS -- All sixteen rocks were analyzed for a suite of trace elements by ICP-MS at the University of Notre Dame (Table 1). Chondrite-normalized REE patterns are shown in Fig. 1 for the basaltic fragments. One sample (**,781**) has much higher total REE and is demonstrably more LREE-enriched than any other sample (Fig. 1; open circle, solid line). Based on petrography and mineral chemistry, Snyder et al. [4] determined that **,781** was an impact melt, and the bulk chemical composition is consistent with a mixed rock with an added KREEP component. This KREEP connection is further supported by the strong enrichment of Li, Be, Rb, Y, Zr, Nb, Ba, Hf, Ta, Pb, Th, and U (elements elevated in KREEP [6]) in this sample over any other basaltic sample (Table 1). Another sample (**,830**) appears to contain a significant KREEP component and was also previously designated an impact melt [4] (Table1).

Seven samples (**,791**, **,792**, **,794**, **,796**, **,797**, **,837**, and **,842**) plot together at La(n) values of 20-35 and exhibit similarly LREE-depleted patterns (Fig. 1; patterned circles) that are consistent with an Apollo 12 ilmenite-basalt affinity

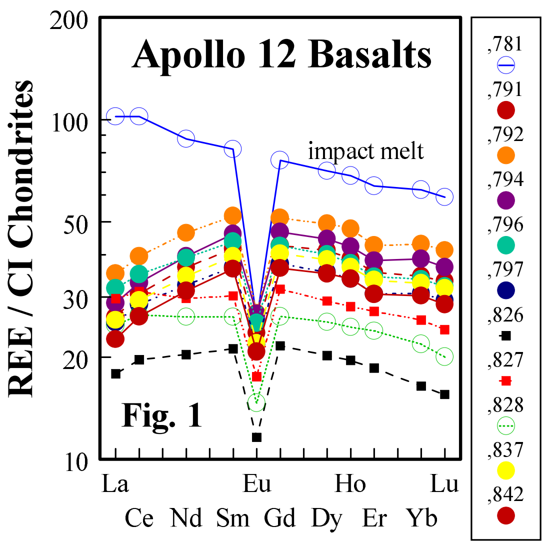
Table 1: Chemistry (in ppm) of >1mm Basalts and Impact Melts from Soil 12001

PM	**,781**	**,783**	**,790**	**,791**	**,792**	**,794**	**,796**	**,797**	**,826**	**,827**	**,828**	**,829**	**,830**	**,837**	**,838**	**,842**
SS	,755	,757	,764	,765	,766	,768	,770	,771	,747	,748	,749	,750	,552	,759	,761	,769
Rock*	IMELT	IMELT	IMELT	BAS/I	BAS/I	BAS/I	BAS/I	BAS/I	BAS/P	BAS/P	BAS/O	IMELT	IMELT	IMELT	IMELT	IMELT
Li	14.83	8.54	8.46	9.44	10.21	10.28	9.81	9.02	5.10	5.65	7.35	10.6	14.08	8.83	9.41	10.04
Be	2.529	0.886	0.750	0.988	1.152	1.757	0.929	0.938	0.51	0.72	0.63	1.04	1.486	0.922	0.989	0.957
Sc	49.8	49.4	55.6	55.7	61.9	50.0	56.8	51.6	25.2	41.6	44.0	53.1	87.0	58.4	44.2	56.8
V	133.6	170.0	157.0	147.1	79.6	116.3	91.7	138.2	51.2	149.1	172.4	188.2	352.2	148.8	89.2	154.1
Rb	5.915	1.608	1.372	0.895	1.247	1.070	1.253	1.085	0.87	1.16	0.97	1.57	2.424	0.944	0.688	0.828
Sr	133.1	105.8	112.8	150.8	165.8	176.7	163.9	139.9	71.5	96.8	93.9	111.3	182.7	143.0	186.6	135.0
Y	103.1	47.7	49.1	63.7	77.6	67.3	62.3	54..4	27.5	37.5	34.4	45.4	77.5	57.4	61.4	55.0
Zr	350.7	139.3	132.5	136.7	177.7	149.6	155.0	125.4	83.1	123.6	103.5	142.9	224.9	127.4	205.1	122.6
Nb	14.93	6.76	2.26	3.61	5.81	6.19	5.56	4.00	4.5	7.0	6.9	9.4	14.70	5.72	8.60	4.65
Ba	267.73	88.74	79.24	61.82	82.47	70.91	80.34	63.40	47.1	74.3	64.3	79.4	129.12	63.94	130.8	55.29
La	24.1	7.80	7.16	6.18	8.30	6.81	7.52	5.97	4.21	7.01	5.86	7.42	11.66	6.07	12.5	5.32
Ce	62.9	20.8	19.8	18.9	24.4	20.4	21.6	17.6	12.1	19.2	16.4	20.6	32.7	18.1	34.4	16.2
Pr	8.12	2.78	2.77	2.87	3.67	3.13	3.18	2.63	1.75	2.71	2.33	2.88	4.44	2.73	4.70	2.47
Nd	40.1	14.6	14.9	16.8	21.2	18.1	17.9	14.9	9.30	13.6	12.0	14.4	24.0	15.8	25.2	14.3
Sm	12.2	4.82	5.11	6.21	7.75	6.87	6.52	5.48	3.15	4.51	3.91	4.70	8.17	5.89	7.70	5.42
Eu	1.44	0.98	1.01	1.32	1.51	1.50	1.41	1.22	0.65	0.98	0.82	0.97	1.64	1.23	2.09	1.16
Gd	14.96	6.50	6.64	8.39	10.11	9.20	8.38	7.41	4.25	6.24	5.19	6.31	10.77	7.95	9.69	7.19
Tb	2.79	1.21	1.25	1.60	1.95	1.72	1.57	1.40	0.78	1.17	0.97	1.21	2.03	1.50	1.71	1.39
Dy	17.3	7.60	7.79	10.1	12.1	10.9	9.82	8.71	4.95	7.16	6.22	7.24	12.6	9.48	10.4	8.62
Ho	3.74	1.63	1.63	2.13	2.61	2.31	2.07	1.86	1.07	1.54	1.34	1.56	2.68	2.01	2.18	1.86
Er	10.21	4.45	4.44	5.68	6.81	6.16	5.52	4.91	2.97	4.36	3.82	4.47	7.19	5.39	5.62	4.90
Tm	1.48	0.65	0.66	0.81	1.00	0.91	0.81	0.70	0.40	0.61	0.52	0.62	1.03	0.78	0.78	0.72
Yb	9.88	4.64	4.34	5.50	6.84	6.18	5.39	4.90	2.61	4.09	3.47	4.02	6.93	5.24	5.23	4.82
Lu	1.45	0.66	0.62	0.82	1.01	0.90	0.79	0.72	0.38	0.59	0.49	0.57	1.01	0.78	0.72	0.70
Hf	9.05	3.64	3.72	4.35	5.35	4.78	4.47	3.99	2.36	3.42	2.98	3.71	6.21	4.06	5.38	3.78
Ta	0.69	0.38	0.094	0.18	0.29	0.31	0.30	0.20	0.27	0.49	0.42	0.47	0.70	0.27	0.46	0.21
Pb	1.77	0.430	0.990	0.274	0.392	0.260	0.373	0.318	0.42	0.58	4.01	0.82	0.624	0.268	0.425	0.249
Th	4.08	1.04	0.93	0.59	0.88	0.69	0.85	0.62	0.52	0.82	0.68	0.87	2.05	1.56	0.62	0.55
U	1.16	0.27	0.24	0.16	0.24	0.20	0.24	0.17	0.18	0.23	0.20	0.24	0.61	0.47	0.15	0.15
Ti (mg)	12.14	14.95	14.41	19.33	22.73	27.49	19.40	20.50	6.66	13.78	13.73	21.45	26.79	23.00	17.89	23.49
Cr	2224	3749	3929	3563	1517	2925	2048	3338	750	3303	3536	4403	7600	3122	1821	3414
Co	33.7	43.2	39.1	49.6	29.0	45.0	32.3	47.6	10.9	39.0	50.3	57.0	94.9	44.6	29.7	46.9
Ni	28.8	36.6	33.8	54.0	13.8	34.1	13.4	40.3	2.3	33.5	69.3	68.6	105.7	41.0	26.1	47.7
Cu	15.2	15.1	16.5	14.9	19.1	17.1	17.8	14.0	18.9	14.9	14.6	21.4	20.6	15.2	14.5	15.2
Zn	10.0	11.7	20.2	14.9	14.9	16.6	15.5	14.0	11.9	14.9	12.5	20.4	24.0	14.4	14.8	15.8
Ga	2.32	2.73	2.78	2.83	3.67	3.31	3.54	2.95	1.32	2.09	2.13	2.51	3.72	2.98	3.83	2.80

*Rock: IMELT = impact melt; BAS/I = ilmenite basalt; BAS/P = pigeonite basalt; BAS/O = olivine basalt.

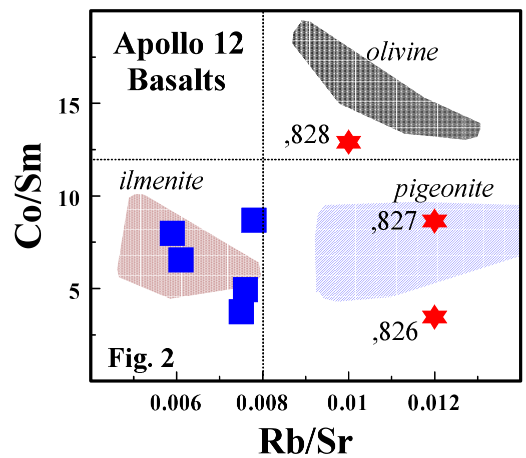
[4, 7]. Relative to other non-impact melt rocks from this suite, these samples also have elevated Ti (19.33 to 27.49 mg), consistent with an ilmenite basalt lineage. These seven mare basalts also have relatively uniform abundances of Li (8.83-10.28 ppm), Be (0.922-1.152), Rb (0.828-1.25 ppm), Sr (135-177 ppm), Ba (55.3-82.5 ppm), Hf (3.78-5.35 ppm), and Pb (0.249-0.392), when compared to the other 1-4 mm fragments (Table 1). On a key petrogenetic plot for Apollo 12 basalts [8], where Rb/Sr is plotted relative to Co/Sm (Fig. 2; patterned squares), these samples plot well within the ilmenite region. However, two of these samples (**,837** and **,842**) were previously determined to have shock and quenched impact features and were classified as monomict impact melts [4]. Thus, these two samples must represent impact melts of a mare basalt target unaldulterated by either upper crustal or meteoritic component.

The two samples that were previously designated [4] pigeonite basalts (**,826** and **,827**) have very low total REE abundances, La(n) = 18-30, and exhibit relatively flat LREE patterns (Fig. 1; filled squares), all typical of pigeonite basalts from the Apollo 12 landing site [7]. Snyder et al. [4] previously designated sample **,828** as an ilmenite basalt, however, the minor-element chemical composition of this sample, including low total REE (La(n) = 25), flat LREE pattern (Fig. 1; patterned square), relatively low Li, Be, Sr, Hf, and Ti (Table 1), high Co/Sm, and high Rb/Sr [7] points to an olivine-basalt lineage (Fig. 2).



PETROGENESIS -- These basaltic fragments are chemically and petrographically indistinguishable from other mare basalts at the Apollo 12 landing site. Thus, their petrogenetic histories also coincide with their respective groupings. The ilmenite basalts in this study are produced by 4-6% non-modal melting of a magma-ocean cumulate source composed of sub-equal amounts of olivine, pigeonite, and clinopyroxene, and containing a small amount of entrained plagioclase (0.5%) [8,9]. Two samples (**,792** & **,796**) have chemical compositions which represent residual liquids from igneous fractionation after melt formation, and one sample (**,791**) has accumulated a significant (5-10%) amount of olivine. Two other ilmenite-basalts (**,794** & **,797**) represent near-primary melts of the source.

The single olivine-basalt and two pigeonite-basalts can be modelled by 5-8% non-modal partial melting of a source similar to that for the ilmenite basalts, albeit richer in clinopyroxene, poorer in pigeonite, and devoid of entrained plagioclase [8]. The composition of olivine-basalt (**,828**) also indicates significant post-melting accumulation of olivine, and pigeonite-basalt **,826** represents a residual liquid after ~20% fractional crystallization. Pigeonite basalt **,827** represents a near-primary melt of the source.



CONCLUSIONS -- With a few important exceptions, our trace-element analyses have confirmed our earlier classification, based on petrography and mineral chemistry, of these sixteen 1-4 mm basaltic fragments from soil 12001. Five samples are relatively high-Ti, demonstrably LREE-depleted, and exhibit other characteristics indicative of pristine ilmenite basalts from the Apollo 12 landing site. Two other samples have relatively low total REE, flat LREE patterns, low Rb/Sr, and other chemical characteristics typical of Apollo 12 pigeonite basalts. One sample has chemical characteristics consistent with an olivine-basalt lineage. All of these basalts were produced by 4-8% non-modal partial melting of a magma-ocean cumulate source composed of variable proportions of olivine, pigeonite, and clinopyroxene with or without entrained plagioclase.

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